Investigation of the bone density in an adolescent idiopathic scoliotic vertebra following a unilateral muscles paralysis

[1]Mohammad Hosseinzadeh Posti, [2]Mohadese Rajaeirad, [3]Amin Komeili, [4]Zeinab Kamal
[1]Mechanical Engineering Faculty, University of Guilan, Iran. [2]School of Mechanical Engineering University of Tehran, Iran. [3]Department of Biomedical Engineering, University of Calgary, Calgary, AB, Canada. [4]Department of Oral and Maxillofacial Surgery, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
Email: z.kamal@umcg.nl

Introduction

Asymmetric loading condition in an adolescent idiopathic scoliotic (AIS) spine alters bone-density, growth-pattern and deformity-progression[1]. Concave-sided paralysis of spinal-muscles in a scoliotic spine alters vertebral loads and decelerate deformity-progression[3]. However, the vertebral bone-density in a healthy and scoliotic spine with intact and unilaterally-debilitated muscles was not investigated. This study hypothesized that fluctuations in the muscular loading pattern change the bone-density in a scoliotic vertebra.

Methods

A L2 finite-element (FE) model was developed using one AIS 11.5-year-old adolescent data (Fig.1). The reaction loads, reported in [3], were applied to the model in three scenarios: normal-spine (N-S), AIS-spine-with-intact-muscles (AIS-In), and AIS-spine-with-unilaterally-weakened-muscles (AIS-UWM) (Fig. 1). Muscle-weakening was simulated [3] by reducing the physiological-cross-sectional-area of the concave-sided multifidus-lumborum and longissimus-thoracis-pars-thoracis muscles to reach 95% loss in their strength. A bone remodelling algorithm ($E \propto \rho^{\alpha}$) using a user-subroutine-program and FE-solver was used to calculate the bone-density in one year[4].

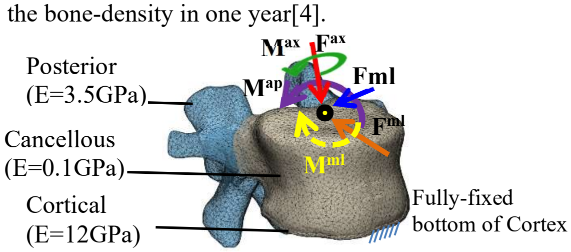

Figure 1. *loads were applied to the L1-L2 disc centroid [3]. The lower surface of the cortical is constrained.*

Results

The maximum values of the bone-density were found to be 0.3129, 0.3171, and 0.3121g/cm^3 for the N-S, AIS-In and AIS-UWM models, respectively (Fig. 2).

Discussion

The higher value of the bone-density at the concave than the convex side in AIS-In model(Fig.2) agrees with clinical observations of less porosity and higher density at the concave than the convex side of lumbar vertebrae in a scoliotic spine[5]. Convex-sided reduction and concave-sided increase in bone-density in the AIS-In model can accordingly diminish and amplify Elastic-modulus and stiffness at the same corresponding sides[6]. This phenomenon can amplify the concave-sided and alleviate the convex-sided strains and stresses, which in turn reinforce bone-density changes. The ratio of the average bone-density of N-S over AIS-In, and N-S over AIS-UWM was found to be 1.013 and 0.997, respectively. In addition, the corresponding change in the bone-density with respect to the average density at each side of N-S, AIS-In, and AIS-UWM was found to be 4.5e-6, 13.4e-6, and 6.7e-6 respectively, which was a concave-sided increase and convex-sided decrease in bone-density. This finding reaffirmed the result of higher symmetry in vertebral stress-distribution in the AIS-UWM than AIS-In model.

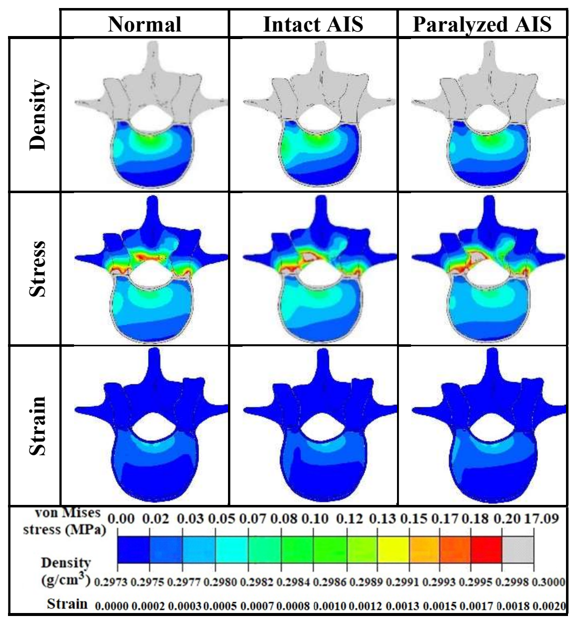

Figure 2. *Distribution of bone-density (1st row),von-Mises stress (2nd row) and strain (3rd row) in L2 for the normal spine, AIS-In and AIS-UWM muscles.*

Conclusion

Results of this study propose that unilateral-weakening of muscles in an AIS spine can increase symmetric distribution of vertebral stresses and bone-density (Fig.2), and reduce the bone-density during growth[1].

References

1. Mehlman C et al. (1997) Am J Orthop 26(11): 798–800.
2. Cheng, J.C et al, J. Spine 22(15): 1716-1721, 1997.
3. Kamal Z et al. (2020) J. Biomech. 111: 109997.
4. Weinans, H., et al., J Biomech 25: 1425-1441, 1992.
5. Shea KG et al.,J Bone Joint SurgAm,86:1000-1006,2004.
6. On the Relation of Bone Mineral Density and the Elastic Modulus in Healthy and Pathologic Bone. Nobakhti S and Shefelbine SJ. Current Osteoporosis Reports (2018) 16:404–410.